PHOTOVOLTAICS FOR THE NORTH: FIVE YEARS OF BREAKING DOWN BARRIERS IN THE NORTHWEST TERRITORIES

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ABSTRACT

Seasonal fluctuation in radiation and other adverse climatic factors have made the implementation of PV challenging in Canada, especially in the North; however, through the development of new technologies adapted to cold climates and the development of expertise in this field, this challenge is being met. This paper reports on the experience and results of *PV for the North*, a program that started in 1993, in response to a need for PV systems better adapted to harsh arctic conditions and a need to raise the awareness of this technology as a viable energy solutions.

This five year program was initiated by the CANMET Energy Diversification Research Laboratory (CERDL), the Aurora Research Institute and the Nunavut Research Institute to address the various issues of importance in the particular context of Canada's north. This program has helped to overcome barriers to increasing the PV market; these barriers include technical, economic and institutional impediments.

The potential market for PV in this region is significant for Canada as none of the communities is currently tied to the North American electrical grid. Instead each community or application must have its own power supply, usually diesel generators, ranging from 1 kW to 20 MW. Many of these applications could benefit from PV, if it was proven to be a reliable technology in arctic conditions.

Experience gained from three different demonstration systems is discussed in this paper. A 3 kW PV array connected to the local diesel grid at Iqaluit allows NRI and CEDRL to evaluate the performance of systems that will have great potential in Canada's north in 15-25 years. The other two are aimed at studying more in depth small PV-diesel hybrid systems that are already cost-effective for many applications.

From a technology point of view, adaptation and innovation were required to come up with viable solutions to practical problems. Two products of particular interest are mentioned in this paper: an insulated battery enclosure incorporating a phase change material that will keep the operating temperature of batteries at or above 0°C all year round and a snow removal technology that helps increase PV array output throughout the winter.

Besides product development, a lot of effort was devoted to testing and modelling. This includes field testing of snow-removal technology under rime conditions and battery testing to evaluate their capacity at cold temperature.

Finally, in order to support a sustainable market in this northern region, information transfer activities were important to the program because this activity informed both technical and non-technical people on issues of interest. This activity includes five regional workshops throughout Canada's north, and the production of a book entitled "PV in Cold Climates" in collaboration with IEA PVPS participants.

The achievements of this program are the result of the diversity of its activities: from market assessment to product development, to demonstrating reliable systems and information dissemination.

1. INTRODUCTION, THE NWT: CHARACTERISTICS AND CHALLENGES

Although the Northwest Territories (NWT) abound with mineral wealth, viable forms of energy supply are limited. In this northern region, 60% of the electricity is produced through diesel generation, which entails high financial and environmental costs. New, clean and reliable renewable energy technologies are in high demand, and solar photovoltaic (PV) energy holds strong potential in the north, both on community diesel-electric grids and in remote off-grid applications.

With a population of 68 000 people, distributed amongst 65 communitites and over 3.3 million km^2, about one third of the total surface area of Canada, the Northwest Territories (NWT) sit on the limit of the Arctic circle between the 60° and 85°N latitude. These communities are not connected to the North American grid. Instead each community or application must have its own power supply, usually diesel generators rated between 1 kW and 20 MW.

Due to their high latitude location, the NWT is characterized by two major aspects that impact the design and operation of PV systems and represent special challenges for Canada: very low temperature during the winter and significant variation in solar radiation from season to season [1].

In response to this need, the CANMET Energy Diversification Research Laboratory (CEDRL), the Aurora Research Institute and the Nunavut Research Institute have conducted *PV for the North*, a research, development and technology transfer program. This program was aimed at reducing the reliance on fossil fuels of Canada's far North. To accelerate the deployment of PV in the NWT, the technical, economical and institutional aspects needed to be addressed. With this in mind, PV for the North has spent the past five years overcoming various barriers by:

- Identifying and evaluating various markets in the Northwest Territories;
- Stimulating PV markets through technico-economic studies;
- Demonstrating and analysing performance of systems operating in arctic conditions;
- Developing technologies better adapted to the cold climates conditions;
- Transferring information and educating potential users and decision makers.

This paper will present an overview of PV for the North activities and summarize the results achieved to date.

2. IDENTIFYING AND EVALUATING MARKETS IN THE NWT

This section will present three market studies that were conducted under PV for the North.

2.1 General Market Study on the Potential for PV

From the beginning, it was necessary to conduct a general market study [2] to evaluate the potential of PV in the NWT while helping to decide on future actions of the program. Table 1 presents a summary of the first evaluation of the market. Note that the potential given here is the technical potential as estimated in 1994.

TABLE 1. Technical potential of PV in the NWT

APPLICATIONS	Technical Portential	Expected Deployment (*)
Diesel Grids	17 MW_p	Long term
Comm. Syst. (VHF)	6 kW_p	Immediate
Comm. Syst. (UHF)	60 kW_p	Short term
Comm. Syst. (M-W)	400 kW_p	Short term
Comm. Syst. (private)	10 kW_p	Medium term
Personnal Comm. Syst.	125 kW_p	Short term
Parks (NWT)	7.5 kW_p	Short term
Hunting and fishing	30 Kw_p	Medium term
Residences	75 kW_p	Medium term
Cathodic Protection	0 kW_p	----
Buoys (navigational)	0 kW_p	----
Fire Tower	7.5 kW_p	Immediate
TOTAL	17 721 kW_p	

(*) Short term (0-5 years); medium term (5-10 years)

2.2 The Diesel Grid Market: A Technico-economic Evaluation for integration of PV

In 1995, a second study focussed on the benefits of using photovoltaics on local diesel-electric grids in the Northwest Territories [3], the market that has the greatest long-term potential in terms of installed capacity in the NWT. This study "values" the addition of PV to the local diesel-electric grids of a typical community, Cambridge Bay.

The results of the study indicated that the principal avoided cost benefits are due to reduced fuel consumption and to a lesser extent, reduced generator start frequency. It was also found that, due to closely matched insolation and diesel plant load during the summer period, PV can be implemented to penetration ratios of up to 0.5 (PV nominal capacity divided by the peak load of the diesel grid) without dumping substantial energy.

In this case, depending on discount and fuel escalation rates, and whether the generator is cold started, results predict benefits ranging from \$2.63/W_p to \$5.75/W_p of PV installed. Results are shown in Table 2 for the case of

Cambridge Bay. These figures do not include any value for environmental benefits and will vary with the insolation, operating stategy used and total electrical load in each community. A sensitivity analysis was carried out on these parameters, but this is not shown here.

For PV to be installed cost effectively on a local diesel grid, the cost of installation of PV must meet the value of avoided cost benefits.

TABLE 2. Avoided cost benefits of PV on the Local Diesel Grid in Cambridge Bay.

Benefit	*Disc. Rate*	*Fuel Inc.*	*$/W$_p$*
Fuel Only	7.5%	3.5%	2.63
	7.5%	5.0%	3.04
	3.0%	3.5%	4.25
*Fuel and Cold-Starts Reduction**	7.5%	3.5%	3.57
	7.5%	5.0%	4.12
	3.0%	3.5%	5.75
600 kW$_p$ PV, 1200 kW Peak Load Diesel Grid Fuel Cost = $0.80/l , Lubricant Cost = $0.03/l of fuel O&M = $7.50/h, Capital Cost = $9.50/h			

Given these figures, it is foreseen that PV could be cost-effective on diesel grid in 15-25 years from now. This will depend on the cost reduction of PV modules and overall installed PV system costs.

2.2 The market for small PV-hybrid systems

The third market study focusses on the market for PV with or in replacement of small fossil fuel generators [4]. The study will consider any applications such as Park facilities, Hunting and fishing camps, cottages and commercial sites that use diesel or gasoline generator rated under 15 kW.

The survey is currently underway and will provide both quantitative and qualitative results with regards to the disposition of the market toward small PV-genset hybrid systems in the Northwest Territories, which in turn will help the industry to better target new clients

3. STIMULATING MARKETS

Based on the general market study, PV for the North decided to perform a number of pre-feasibility studies for specific applications. This activity was aimed at promoting use of PV for applications that have near-term potential in the Northwest Territories. Two of the five studies performed are described in this paper.

3.1 The Case of Tanquary Fiord Park Facility

The Canadian Parks Service operates many facilities throughout the Northwest Territories, several of which are used only on a seasonal basis. The seasonal camps generally use a generator as a source of electricity; this is costly, predominantly because of the high price of fuel at the sites.

The park facility at Tanquary Fiord, on Ellesmere Island, used to be powered only by generators until CEDRL conducted a pre-feasibility study of the application of PV at the site [5]. This study concluded that a PV-genset-battery system was cheaper than conventional genset alone or genset-battery system, on a life cycle cost basis. Following the conclusion of this study, the Canadian Parks Service proceeded with the installation of a PV-wind-genset hybrid system in 1994.

The system features a tracker that allowed the 576 W$_p$ PV array to provide about 45% of the total energy required in the first two years of operation. This reduced the average generator operating time from 18 hours to 2.2 hours per days [6], providing not only economic benefits to the Parks Service but also a better quality of life to the people on site.

This system also showed that PV systems work well and economically in the arctic. Besides this positive experience has convinced Canadian Parks Service to adopt PV technology at other facilities in the west of Canada.

3.2 The Case of NorthwesTel's VHF Repeater Sites

In its general market study in 1994, PV for the North had identified NorthwesTel's telecommunication facilities as the application with the most potential for PV in the near-term. NorthwesTel (NWTel) had little experience with this technology; by preparing a pre-feasibility study targeting NWTel's VHF telecommunication facilities, PV for the North provided an independent assessment of the benefits to convert these power supplies to PV [7].

This study showed NWTel the important economic advantages of PV over the primary batteries: due to the remoteness of the sites, the PV system initially cost about the same as the primary batteries that needed to be replaced every year. In the two years following the study, NorthwesTel converted 9 of their 11 VHF sites to PV and is now considering PV for their larger UHF and microwave repeater sites.

4. DEMONSTRATING AND ANALYSING PERFORMANCE OF PV SYSTEMS

In order to increase the visibility and the credibility of PV systems, PV for the North has supported three demonstration systems. These systems provide working examples of PV systems in cold climate and some valuable data for long-term performance evaluation.

The three systems are:

- A grid connected system in Iqaluit
- An autonomous PV system and a PV-wind-diesel hybrid test bed in Inuvik
- A UHF site operated by NorthwesTel. PV for the North contributed to convert one of the NWTel's telecommunication site, originally powered by a diesel generator and a battery bank, to a PV-diesel-battery system.

These demonstration systems are described in more detail in the following sections.

4.1 Diesel Grid-connected Demonstration System in Iqaluit

As mentioned earlier in this paper, grid-connected systems on local diesel-electric grids hold the greatest long-term potential for PV in the future of the NWT. Despite the fact that, presently, it is cost-effective to install grid-tied systems, it is important to have data on its long-term performance. A 3.2 kW PV array was installed and fully monitored in Iqaluit. This system (Fig.1) will provide a valuable insight into the operation of such systems on a diesel grid at high latitudes.

Beyond its value as a state-of-the-art demonstration of the technology, this system provides high visibility for the technology as the modules are mounted on the facade of the Nunavut Campus of the Arctic College. The data obtained from the monitoring will be used to analyse the performance of the system in general as well as the efficiency of each components individually and will help to improve the models incorporated in simulation tools.

Fig.1 The 3.2 kW PV array mounted on the facade of the Nunavut Arctic College in Iqaluit is connected to the local diesel-electric grid.

4.2 Stand-alone and Hybrid Demonstration Systems in Inuvik

The second demonstration set-up by the program includes two systems: a small stand-alone PV system and a PV-wind-diesel hybrid test bench. The stand-alone system includes a 720 W_p of PV (fixed array facing South) and a battery bank. During the summer, the system powers the radio of the Parks Canada regional office used to communicate with other Parks' facilities outside Inuvik.

While the autonomous system is dedicated to a given application, the hybrid one serves a different purpose: it includes many features that makes it an interesting research test facility. The main features of the hybrid system are:

- A 360° tracker with 720Wp of PV (Fig. 2);
- A battery enclosure with phase change material (Fig. 4);
- A resistive element that can use the excess energy from PV array to heat batteries is also incorporated in the battery enclosure;
- An 850 W wind turbine;
- A remote control system to modify some parameters or setpoints via modem.

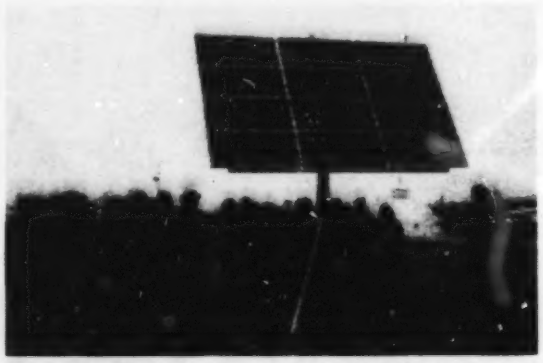

Fig.2 The 360° azimut tracker is one of the features of the PV-wind-diesel hybrid system in Inuvik.

The solar radiation on both the tracking array and the fixed array are monitored and will allow comparison of the energy collected by each type of array. This will help evaluate benefits of a tracking device compared to a fixed array.

The battery enclosure installed as part of this system is a unit that was developed under the PV for the North program. It includes insulation and some water as a phase change material that helps to keep batteries at or above 0°C (refer to section 5.1). This test bed facility represented a good opportunity to design and test such a unit. Given the high latitude and cold conditions of the site a 1.5m x 1.5m x 1.5m enclosure, shown in Figure 4, was required to contain the batteries of both the stand-alone system and the hybrid system. The enclosure also contains 0.25 m of insulation on all sides and 500 litres of water in plastic containers.

As a test bed, the hybrid system is not dedicated to power any critical load and remains versatile enough to allow testing control set points or new features that could be monitored along with the current installation.

4.3 NorthwesTel's telecom site

Another demonstration system partially supported by PV for the North is a NorthwesTel's UHF repeater site in the Nahanni National Park (Fig. 3). PV for the North contributed to this demonstration project in order to provide an incentive for NWTel to embark in the process of conversion of their UHF and microwave sites from diesel to PV-diesel hybrid system, and because of the high potential for PV with this application in the north.

This project involved three parties who had a common interest: seeing more of these sites converted to PV. The three parties, who contributed with equipment, funds, and labour, are: the owner (NorthwesTel), PV for the North, and a supplier (Soltek Solar Energy), respectively.

Fig.3 A 1.5 kW PV array was added to existing diesel-battery system powering a NWTel's telecom site in Nahanni National Park in the Rockies, NWT.

5. DEVELOPPING AND MODELLING TECHNOLOGIES

To use PV in northern climates, components must be suited for operation under severe environmental conditions. PV for the North has worked to overcome some of the problems related to the operation of batteries and PV modules under these harsh conditions. More specifically, two products were developed, modelled and tested under the aegis of the program: an insulated battery enclosure incorporating a phase change material that will keep the operating temperature of batteries at or above 0°C all year round and a snow-removal technology for modules that helps increase PV array output throughout the winter.

5.1 The Phase Change Material Battery Enclosure

Since temperatures during the winter are well below 0°C in most of Canada and battery capacity significantly decreases at such temperatures, PV for the North has evaluated ways to improve battery performance throughout the winter while reducing the cost associated with oversizing the battery bank.

The battery enclosure developed by CEDRL staff includes a phase change material (PCM) that can maintain the battery temperature above a given temperature throughout the winter. When using water as a PCM, its freezing point (0°C) can be the lowest temperature reached in the enclosure during the winter if the enclosure is properly sized [8]. Figure 4 illustrates the product. CEDRL has also carried out the field tests used to validate the models used to design the enclosure [9].

The battery enclosures have now passed the stage of development: they are commercially available from Soltek who manufactures and customizes these battery enclosures to address the needs of their clients. Several custom units have been sold to date.

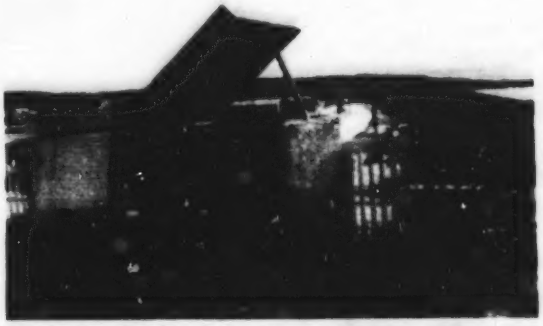

Fig.4 An insulated battery enclosure with water containers can maintain battery temperature at or above 0°C throughout the winter.

5.2 The Snow-removal Technology for PV modules

A PV snow-removal technology was developed and patented by TN Conseil, a Canadian company. The technology consists of solar thermal collector mounted on the rear face of the panel that facilitates the removal of snow (Fig.5). To evaluate the performance of this product, PV for the North, has performed extensive field tests and modelling of this technology. The technology successfully demonstrated that it accelerates snow removal. Additional field tests are currently under way to evaluate how this technology will perform in rime prone sites.

Fig.5 The TN Conseil panel (top center) melts off the previous night's snow fall while regular panels remain covered (bottom) [3:20 PM, March 6, 1995]

6. TRANSFERING INFORMATION

During the past five years, PV for the North has disseminated information about the PV technology by:

- Publishing articles in various magazines and newspapers to raise the awareness of the technology;
- Conducting training workshops in the NWT;
- Publishing and distributing technical reports to assist engineers and decision makers;
- Providing training to Northerners at CEDRL;
- Preparing a video aimed at informing the public;
- Preparing a comprehensive book about the use of photovoltaics in cold climates and case studies summarizing lessons learned in several countries in the world.

All of these information transfer activities have raised the awareness of the technology and the potential for its application in the Northwest Territories and the rest of Canada. Many of the documents will remain tangible results that will continue to be available references and promote the use of PV to potential end-users in the future.

This is especially true for the "PV in Cold Climates" book in preparation [10] that will inform both decision makers and engineers, help them understand the issues of PV applications in cold climates and provide reliable information on the current status of the technology well beyond the end of the PV for the North program. The book will also have an impact beyond the limits of the Northwest Territories, yet Canada's, as it is the result of an international collaboration between Austria, Canada, Denmark, Finland, Norway, Sweden, Switzerland, United Kingdom and United-States as part of the International Energy Agency Photovoltaic Power Systems (IEA PVPS) agreement.

7. CONCLUSIONS

Increasing the penetration of PV technology in the Northwest Territories to reduce reliance on fossil fuel was the main objective of PV for the North. After five years of activities, it is clear that PV for the North has made and helped others to make a step in that direction: the knowledge acquired though experimentation and markets assessment, the information transferred to Northerners, and the technologies developed, contributed to breaking down barriers to the implementation of PV technology in the Northwest Territories.

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